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955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D.C. 20024

B70 09013

SUBJECT: A Survey of the Orbital Collision Hazard for a Manned Space Station Case - 105-6

DATE: September 4, 1970

FROM: H. B. Bosch

ABSTRACT

A survey of some recent studies pertinent to the collision hazard between a manned space station and other space objects shows that, in spite of different collision models and different assumptions concerning the distribution of orbits, the results of these studies are similar. The statistical predictions indicate that, for each 100 missions of ten years' duration in a 55°/500 km (270 nm) circular orbit, a space station can expect to experience two to four collisions with other objects in orbit. These predictions are believed to represent an upper bound.

The probability of collision depends primarily on (1) spacecraft size, (2) mission duration, and (3) the number (or density) of objects in the vicinity of the spacecraft orbit. It is noted that the total number of objects in earth orbit has almost doubled in the past four years.

Surveillance of objects in the region of the sky traversed by the space station, coupled with orbit prediction, can give enough advance warning of an impending collision to allow for the execution of some avoidance maneuver. It is noted that such predictions were made by NORAD for the Gemini missions.

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MEMORANDUM FOR FILE

INTRODUCTION

The possibility of a collision between a space station and other objects in earth orbit deserves attention because of (1) the anticipated long duration of such a mission, (2) the large size of the space station, and (3) because the station will be manned. Therefore a brief survey was made of studies which might be pertinent to a statistical estimate of this collision hazard.

The Aerospace Corporation (Reference 1) did a preliminary analysis of the problem for a 10 year space station mission. An internal study at MSC (References 2 and 3) considered the more complex problem of a ten year mission during which the configuration evolves from a station to a base. A short analysis was also done at MSFC (Reference 4) specifically for an 8 month Skylab mission. This analysis is currently being applied to a space station mission.

Less recently, studies were conducted by TRW to assess the collision hazard for a hypothetical Apollo mission (References 5 and 6) and for specific Gemini missions (Reference 7). The basic methods used in these studies are described in the Appendix.

SATELLITE POPULATION ASSUMPTIONS

In all of these studies the population of orbiting objects is assumed to remain static as of a certain epoch. An examination of the recent history of objects listed by GSFC in Reference 8 showed that this number has nearly doubled in the past four years, as shown on Figure 1. Although GSFC lists only about one-half of all objects which are tracked by NORAD, the trend shown is believed to represent the actual trend. Whether the rate of increase will continue as shown is difficult to tell, primarily because the satellite launch rate depends on economic, political and military factors.

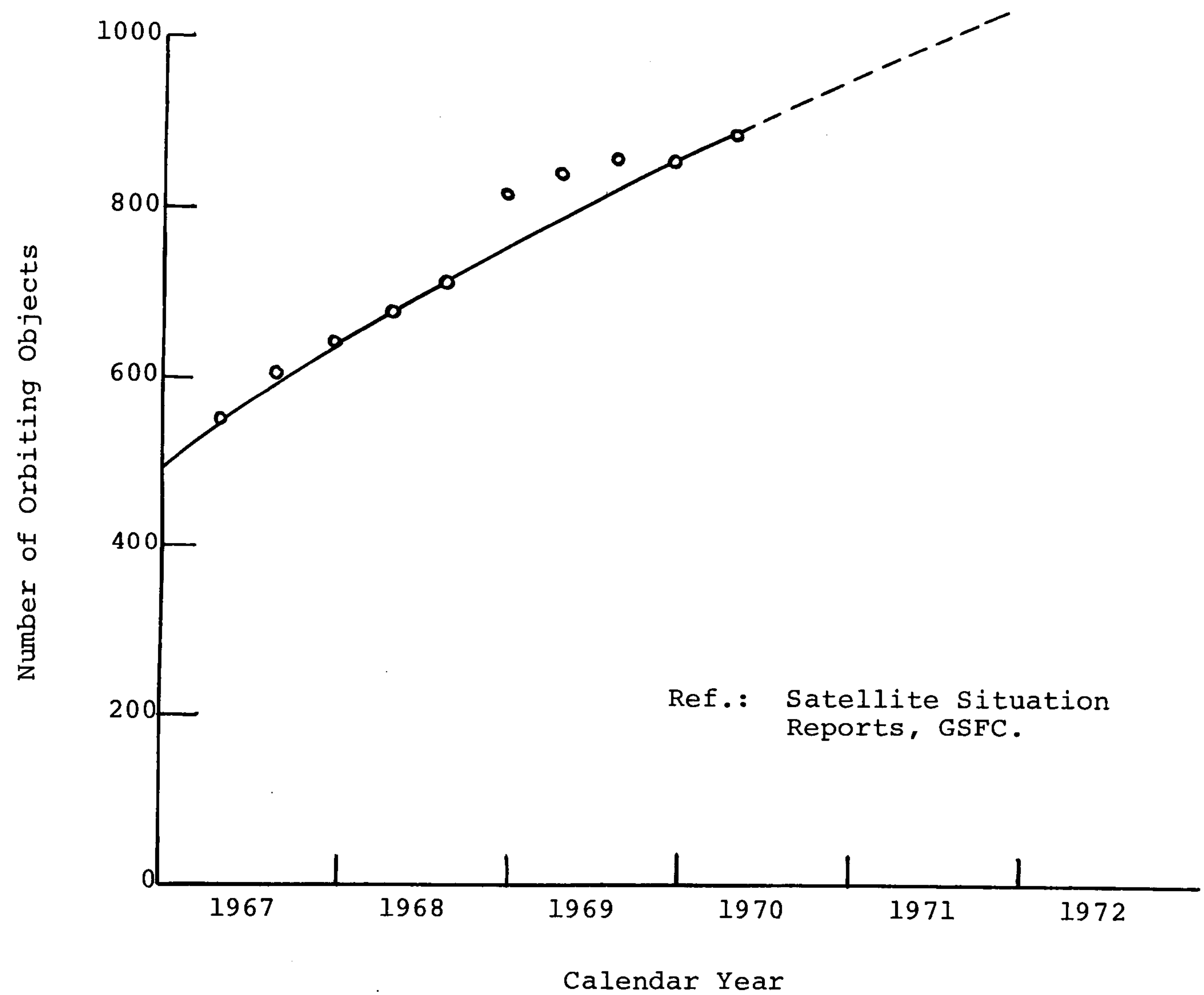

FIGURE 1. POPULATION GROWTH OF ORBITING OBJECTS.

It is also difficult to tell -- without resorting to extensive data processing -- whether the same increase is present in the altitude range of interest to the space station and other manned missions. For example, it is noted in Reference 2 (p. 2) that the number of objects whose orbital altitudes bracket 500 km (270 nmi) actually decreased by 5% between 1966 and 1969, in spite of an increase in the total number of objects in earth orbit.

Due to these difficulties it can only be stated that numerical results of collision hazard studies based on a current object count cannot remain valid indefinitely.

DISCUSSIONS OF RESULTS

As is described in the Appendix, the Aerospace study is based on a model which assumes the hazardous orbits to be distributed uniformly within a certain torus. TRW's model assumes the orbits to be grouped in bands according to histograms (bar charts). In the MSC analysis, although an actual distribution of orbit altitudes and eccentricities is used, it is assumed that the distribution in which an orbit crosses the spacecraft orbit plane has no effect on the collision statistics.

The numerical predictions of collision probabilities from the four major studies (References 1, 3, 4, and 5) are summarized on Table 1. In each study, a characteristic dimension is assumed to represent a collision distance between the spacecraft and another object. The characteristic dimension of 115 meters for the MSC model is considered typical of the varying dimensions which they assume for the space station. For comparison purposes, the last column shows the probabilities extrapolated to a 10 year duration and a characteristic dimension of 103 m. This extrapolation is justifiable since all the models assume a constant object population and a collision probability proportional to a crossectional area.

Note that the TRW results are for orbits at 643 km and 964 km (400 and 600 statute miles, respectively, assumed for hypothetical Apollo missions) whereas the space station results are for 500 km (270 nautical miles). It was observed in Reference 6 (p. 26) that there were almost twice as many satellites around 643 km and 964 km as there were around 500 km. This may partly explain the higher extrapolated probabilities resulting from the TRW study. With these qualifications, it can be said that the studies, which are based on different models and assumptions, result in similar probabilities for similar missions.

TABLE 1. COLLISION PROBABILITY ESTIMATES (SUMMARY)

Source	Spacecraft Orbit	Mission Duration	Characteristic Dimension	Collision Probability	Extrapolated Probability*
Aerospace	55°/500 km	10 years	103 m	.026	.026
MSC	55°/500 km	10 years	115 m	.031	.025
MSFC	435 km	8 months	100 m	.001	.016
TRW	30°/643 km	12 days	38 m	3.7×10^{-5}	.081
	30°/964 km	12 days	38 m	3.1×10^{-5}	.068

*Extrapolated to 10 years and 103 m.

The numerical values for the probabilities may be reduced by refining the collision model. For example, by considering three classes of object sizes instead of representing all objects by one characteristic dimension, and by considering an "average" instead of maximum projected area for the space station, MSC has recently reduced their ten year collision probability prediction from .03 to about .006. This reduction, as a result of considering a more realistic crossectional area, indicates that the values shown on Table 1 represent a somewhat pessimistic upper bound to the collision probability.

A more realistic estimate might also be obtained by refining the traffic model: that is, using an actual distribution of orbits rather than assuming statistical properties for such a distribution. The benefits of such an approach seem questionable, however, in view of the fact that three basically different sets of assumptions (see Appendix) lead to such similar results (see Table 1). Thus it appears that the probability of a collision occuring is primarily dependent on (1) the size of the spacecraft, (2) the duration of the mission, and (3) the number or density of objects in the region of interest in the sky.

COLLISION AVOIDANCE MANEUVERS

A collision probability of .001, say, must be interpreted to mean that, out of 1000 ten-year missions in 55°/500 km circular orbits, one mission is likely to experience a collision. But the number .001 contains no information on whether the unlucky flight will be the first or the 1000th. Thus, with a nonnegligible probability, some form of collision avoidance maneuver may some day be called for.

Brief calculations at Bellcomm (Reference 9) have shown that, in the case of Skylab, there appears to be sufficient residual CSM-RCS fuel to perform any required avoidance maneuvers. The onboard autopilot is adequate for attitude hold while an astronaut manually performs a translation maneuver. Such a maneuver is based on the assumption that NORAD tracking and orbit determination will give one or two days' warning of a potential encounter.

This raises the question of whether an onboard capability should exist to determine the orbits of nearby objects which are too small to be tracked from earth, or whether structural design considerations should include damage from very small objects. Comparing collision probabilities for objects of different sizes might provide some basis for examining these questions.

It is also obvious that removal of spent rocket stages or inoperative satellites from orbit would help to reduce the collision hazard, and that reusable boost stages would have the same effect.

CONCLUSIONS

In spite of different approaches, the numerical predictions which result from the several studies are remarkably similar. They indicate a finite, non-negligible collision hazard for a large long-duration spacecraft such as a space station or base. A total launch rate continuing at its present level (100 to 120 launches per year) indicates an increasing overall population of objects in earth orbit.

Finally, it appears advisable to have surveillance over objects which present a potential hazard to a space station (especially during manned periods) in order to provide advance warning of impending collisions. This was done by NORAD in the case of Gemini missions, for example (Reference 7).

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APPENDIX

COLLISION MODELS

In the main method used by Aerospace (Reference 1), only those objects are considered whose orbits intrude into a geocentric torus surrounding the space station orbit. Each object satisfying this criterion is given a numerical weight, computed as that portion of its orbital period during which the object dwells inside the torus. By considering these objects to be uniformly distributed throughout the torus, a weighted object density is calculated. The volume of space which the station "sweeps out" during its entire mission is computed from a characteristic dimension of the station. Finally, the expected (or average) number of collisions for the mission is arrived at as the product of this "sweep volume" with the weighted object density.

In TRW's primary method (Reference 5), a catalog* of orbiting objects is examined and histograms (bar charts) are made of the distribution of the orbital parameters. A hypothetical population of objects is then assumed to be distributed in certain "bands" according to these histograms. The number of object crossings of the spacecraft orbit during the mission is established, taking into account the precessions of ascending nodes and lines of perigee. Since not every orbit crossing is a potential collision, this number is reduced by a "beat frequency" determined from the orbital period differences between spacecraft and object. This number is further reduced by the probability of the spacecraft being at the orbital intersection when an object is crossing. Finally, by assigning a characteristic dimension to the spacecraft, a statistical prediction is arrived at for collisions with these hypothetical objects.

MSC has been using this method with minor modifications (References 2 and 3). To reflect the configuration changes as the space station is built up to a space base, as well as during periods of rotation for artificial gravity, they employ a characteristic dimension which varies over a ten year period.

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*Such as the daily "NORAD Element Summary" tapes or the briefer, bi-weekly NASA/GSFC "Satellite Situation Reports".

In the analysis performed at MSFC (Reference 4), the probability is calculated that the spacecraft and object orbital radii will have the same magnitude near the line of intersection of the orbit planes. Also calculated is the probability that the spacecraft and an object will be near the intersection point simultaneously. This is done for every object whose altitude range (between perigee and apogee values) includes the altitude of the spacecraft orbit. However, the effect of the mutual inclination of one orbit plane to another is not included in this analysis. (For example, an object whose orbit is nearly co-planar with the spacecraft orbit poses a greater collision hazard than one whose orbit is nearly perpendicular to the spacecraft orbit.)

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